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SIMILITUDE IN HYDRODYNAMIC TESTS INVOLVING PLANING

By M. F. Gruson

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Tests of small models of hulls are of major importance. Indeed, empiricism can be considered to be almost the only guide for the hull designer and, on the other hand, tests in full size can be considered only as altogether exceptional because of the difficulties they involve and above all because of the capital risk involved.

Shipbuilders have understood the importance of this for a long time and since the end of the nineteenth century many towing tanks have been built (the Glasgow tank, in 1882).

The methods of testing followed on these towing tanks seem practically perfect, especially in connection with the prediction of the maximum speeds of full-size ships. In fact, in the case of a series of vessels of the same construction, although the measured maximum speeds in full size showed differences of 6 percent, the figure deduced from the tank tests lay near the mean of these speeds. Unfortunately, as we shall see later, these methods are poorly suited to the case of high-speed hulls operating as planing craft: hulls of speedboats, hulls and floats of seaplanes. This circumstance may explain in part the lack of enthusiasm - in France, especially - that the method of testing small models has met with among seaplane people.

The resistance to forward motion of a partially immersed hull may be considered, as a first approximation, to be made up of a resistance of impact (form resistance) and a viscous resistance (friction and eddies).

The impact resistance manifests itself by the formation at low speeds of a bow wave forward and a hollow at the stern; at high speeds by the formation of two systems of waves: the diverging waves and the transverse waves. This resistance is the sum of the components, parallel to the direction of motion, of the normal pressures on the hull.

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*"Sur la Similitude dans les Essais Hydrodynamiques Concernant L'Hydroplanage." Extrait des Rapports des Journees scientifiques et techniques de mecanique des fluides de L'Universite de Lille, April 1934.

If one passes from the model to a hull of linear dimensions n times greater, the speeds are connected by the law of mechanical similitude:

$$\frac{V^2}{L} = \text{constant}$$

L = some linear dimension

The normal forces given by the hydrodynamic equations (perfect fluid) also follow the law of dynamic similitude (Reech's method) and are multiplied by n^3.

The viscous resistance manifests itself by the formation along the surface of the hull of a layer disturbed by the friction (laminar layer forward, then turbulent layer); this layer is extended at the stern by eddies.

Unfortunately, the criterion for similitude of the phenomena of viscosity is no longer the law of mechanical similitude, but the Reynolds criterion:

$$\frac{VL}{\nu} = \text{constant}$$

Under these conditions the method used in ship tests to convert from the resistance of the model to the resistance of the full size is as follows: The total resistance of the model is reduced by the resistance of friction, this latter being computed for the wetted surface by means of an empirical formula for friction. The remainder is considered as the form resistance (wave-making resistance) of the model. When multiplied by n^3 (law of mechanical similitude) it gives the wave-making resistance of the full size. The total full-size resistance is finally obtained by adding to this wave-making resistance the full-size frictional resistance computed by means of a formula analogous to the preceding.

This method thus assumes that the phenomena of waves and of viscosity are independent of one another; the accuracy of the results depends on the formulas used for friction. These formulas are based on tests made in the tank on submerged plates (tests by Froude, tests by Gebers).

The correction for frictional resistance just described is, as we have said, difficult of application to high-speed hulls, and in particular, to the hulls and floats of seaplanes. The wetted surface of this type of hull varies rapidly with the speed; furthermore, it is difficult to determine it with precision at the high speeds of planing. Finally, also, at high speeds, friction appears not only as part of the total resistance but also as the exciter of a pitching moment that causes the trim angle of the hull to vary with the scale. This change of trim in turn acts on the system of waves and the mechanical similitude of the wave-making resistance is disturbed. (It is the recognition of this fact that has led us at the hydrodynamic laboratory at Saint-Cyr to test hull models at fixed trims, measuring the resistance and the trimming moment.)

The Hamburg tank has made two series of comparative tests on this subject, the results of which are particularly conclusive. The first series (reference 1) was on four geometrically similar floats that had respectively, the following lengths: 3.90 m, 2 m, 1 m, 0.50 m (12.79 ft., 6.56 ft., 3.28 ft., 1.64 ft.).

The four curves of resistance, expressed as kilograms per ton of displacement (mechanical similitude), as a function of speed, are given in full lines on figure 1. It will be seen from these curves that the maximum resistance varies from 293 kg for the 3.90 m float to 362 kg for the 0.50 m float; at a speed of 10 m/s, the resistance of these same floats varies from 184 kg to 287 kg, or differences of 23 percent and 56 percent, respectively.

The second series of tests (reference 2) was on five models of hulls having the following ratios to the full size: 1/1, 1/3, 1/6, 1/9, 1/12. The characteristic curves, also expressed in kilograms per ton, are shown in full lines on figure 2. If one excludes the full-size model for which the maximum resistance was not reached on the tests, one finds, nevertheless, that the maximum resistance is 218 kg for the 1/3 size model and 253 kg for the 1/12 size; at a speed of 13 m/s the resistance varies from 125 kg to 177 kg. The differences are thus 16 percent and 42 percent, respectively, for models of which the ratio of the dimensions is 4.

From these tests it is plain that the correction for mechanical similitude, the only one that thus far appears to have been applied abroad in connection with tests of

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kg × 2.20462 = lb. m/s × 3.28083 = ft./sec.

seaplane hulls, is entirely inadequate, especially at speeds greater than that corresponding to the maximum resistance. In this manner we have been led to the thought that the viscous resistance - considered, until very recently, as negligible at high speeds - might on the contrary be preponderant at those speeds.

Accordingly, we have been led to the following approximate method of correction: We divide the characteristic resistance speed curve given by the model tests into two parts: the ascending branch, corresponding to speeds lower than that of the maximum resistance, and the branch corresponding to speeds higher than that of the maximum resistance. We assume that the first branch corresponds solely to wave-making resistance, friction being negligible. By this hypothesis, the first branch can be converted from model scale to full size by the simple application of the law of mechanical similitude.

For the second branch, we assume that the resistance can be considered wholly as frictional resistance and that it follows the particular law of similitude given by Gebers' formula for frictional resistance:

$$R = 0.0103\, l^{-0.125}\, V^{1.875}\, \frac{\gamma}{g}\, \nu^{0.125}\, S$$

in which,

R is the frictional resistance

l, the wetted length

V, the speed

S, the wetted surface

For a model having a linear scale of l/n, this formula becomes:

$$R_m = 0.0103 \left(\frac{l}{n}\right)^{-0.125} \left(\frac{V}{\sqrt{n}}\right)^{1.875} \frac{\gamma}{g}\, \nu^{0.125}\, \frac{S}{n^2}$$

(the speed following the law of mechanical similitude $\frac{V^2}{L}$ = constant).

To convert to scale size, it therefore is sufficient to multiply the ordinates of the second branch by the coefficient $\frac{R}{R_m} = n^{2.8125}$.

If the second branch has already been converted to the full size according to the law of mechanical similitude, or - what is the same thing - if the resistance is expressed in kilograms per ton, the foregoing coefficient will become:

$$\frac{n^{2.8125}}{n^3} = \frac{1}{n^{0.1875}}.$$

Finally, if the passage of the hull from the first regime (immersed) to the second (planing) is definite, a first approximation to the maximum of the curve at full size can be given by extrapolating the second branch of the curve converted at $n^{2.8125}$ up to the first branch converted at n^3.

The method just described has been applied in figures 1 and 2 to the curves published by the Hamburg tank. It can be seen in these figures that the widespread sheaf of experimental curves is, by this method, condensed about the curve corresponding to the full size; it can also be seen in figure 1 that the maximum of the full-size curve may be approximated, by this method, with very good accuracy.

Accepting the crudeness of the hypothesis, we believe that such a method of conversion should be considered only as a method of first approximation that may be used provisionally until the laws of planing surfaces are established physically. We wish to present the method only in that light.

Translation by Starr Truscott,
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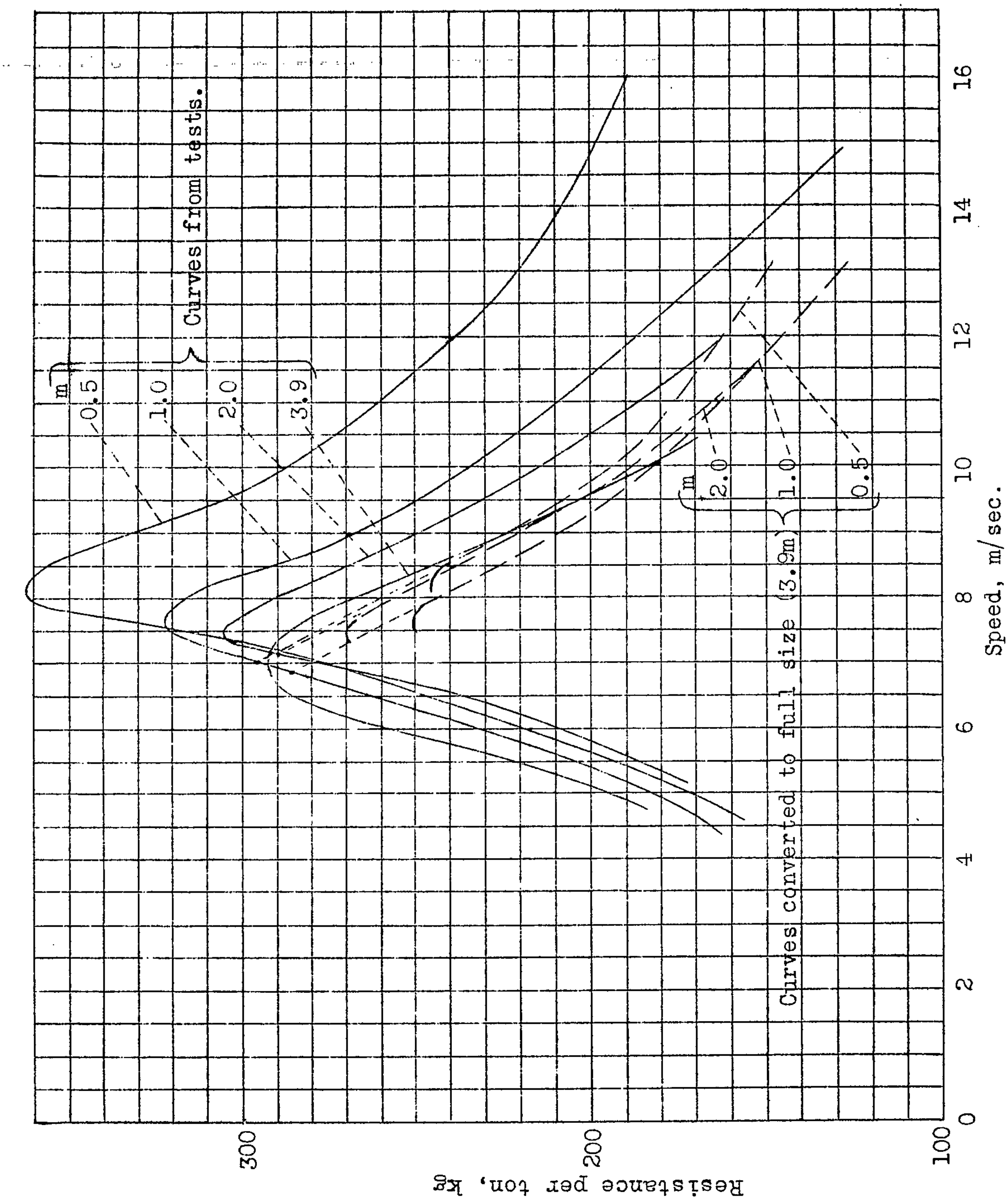
REFERENCES

1. Herrmann, G., Kempf, G., and Kloess, H.: Tank Tests of Twin Seaplane Floats. T.M. No. 486, N.A.C.A., 1928.

2. Sottorf, W.: Scale Effect of Model in Seaplane-Float Investigations. T.M. No. 704, N.A.C.A., 1933.



Resistance per ton, kg
100
200
300
Speed, m/sec.
0
2
4
6
8
10
12
14
16
Curves from tests.
m
0.5
1.0
2.0
3.9
Curves converted to full size (3.9m)
m
2.0
1.0
0.5

Figure 1.

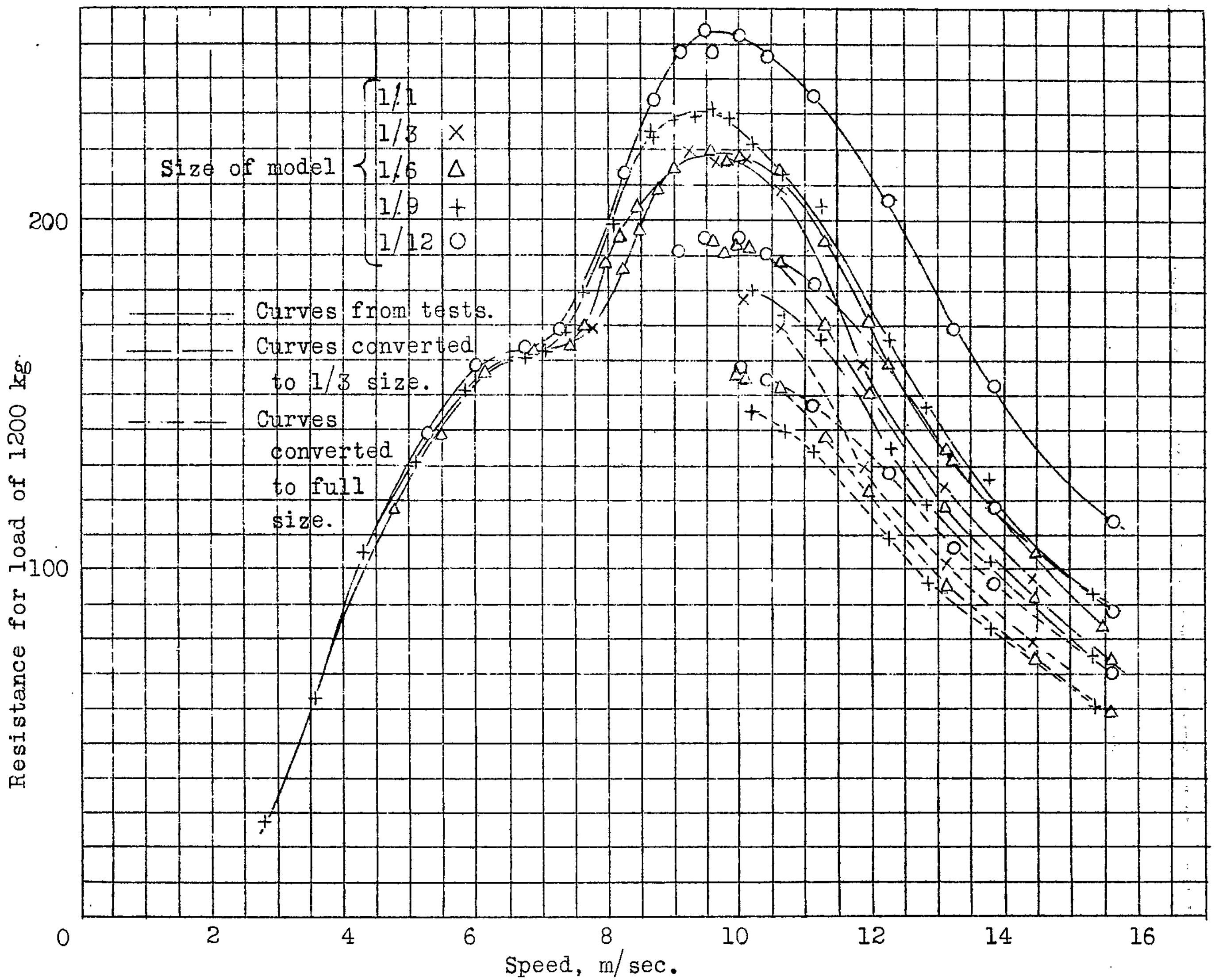

Size of model
1/1
1/3 ×
1/6 △
1/9 +
1/12 ○
Curves from tests.
Curves converted to 1/3 size.
Curves converted to full size.
Resistance for load of 1200 kg
200
100
0
2
4
6
8
10
12
14
16
Speed, m/sec.

Figure 2.